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Motion Tracing System For Ultrasound Guided HIFU

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Abstracts: One main limitation in HIFU treatment is the abdominal movement in liver and kidney caused by respiration. The study has set up a tracking model which mainly compromises of a target carrying box and a motion driving balloon. A real-time B-mode ultrasound guidance method suitable for tracking of the abdominal organ motion in 2D was established and tested. For the setup, the phantoms mimicking moving organs are carefully prepared with agar surrounding round-shaped egg-white as the target of focused ultrasound ablation. Physiological phantoms and animal tissues are driven moving reciprocally along the main axial direction of the ultrasound image probe with slightly motion perpendicular to the axial direction. The moving speed and range could be adjusted by controlling the inflation and deflation speed and amount of the balloon driven by a medical ventilator. A 6-DOF robotic arm was used to position the focused ultrasound transducer. The overall system was trying to estimate to simulate the actual movement caused by human respiration. HIFU ablation experiments using phantoms and animal organs were conducted to test the tracking effect. Ultrasound strain elastography was used to post estimate the efficiency of the tracking algorithms and system. In moving state, the axial size of the lesion (perpendicular to the movement direction) are averagely 4mm, which is one third larger than the lesion got when the target was not moving. This presents the possibility of developing a low-cost real-time method of tracking organ motion during HIFU treatment in liver or kidney.

I. INTRODUCTION

There are several limitations for high intensity focused ultrasound (HIFU) treatment. Firstly, Ultrasound beam can't propagate through organs which are filled with air such as lung or bowel1. Secondly, obstructions such as bone can absorb or reflect the ultrasound beam, which may cause damage to surrounding healthy tissue2. Thirdly, respiratory induced organ motion could compromise treatment efficacy during sonication. What's worse, the displacement of organs due to breathing can lead to unexpected ablation on normal tissues (FIGURE 1). Some cases of mis-targeting have been reported by Allen3 in HIFU treatment of liver metastases.

Several studies[4] have shown that the pancreas, the liver and other abdominal organs can move as much as 20 mm over the breathing cycle with the motion speeds up to 15 mm/s. The motion compensation is particularly necessary for the treatment of abdominal tumors where the respiratory induced motion is quite obvious. Correcting motion is an adaptive way to ensure that the entirety of the targeted volume has been properly and totally treated and it is also the only way to make sure that no surrounding healthy tissue has been damaged.

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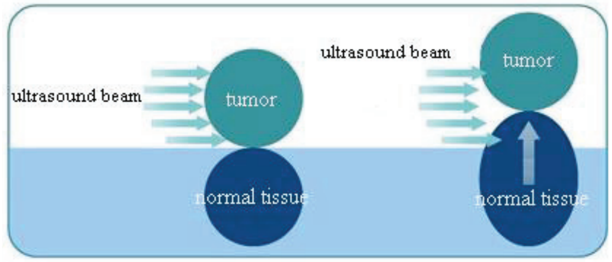

FIGURE 1: Tissue ablation on normal tissues caused by organ motion

There are two ways to achieve that, via electrically phased-array transducers or via mechanically robotic controlled device. Multi-element transducer is a large transducer array. The focal point of multi-element transducer can be changed more than 40 times per second to follow any complex trajectory[5]. The trajectory of focal point can be adjusted by programming each electronic channel. The beam-steering could also achieved by robotic controlled single-element HIFU transducer, which will provide a wider range but a slow beam-steering speed.

Based on previous ultrasound image-guided FUS tracking system[6], in this paper, a dedicated designed respiratory motion modal was built to provide a circumstance which is more close to the motion caused by human breath. Consequently, the modal was used to design tracking experiment using a tissue mimicking phantom. The performance of the respiratory motion modal was tested and the motion simulator was proved to be sufficient to be used to mimick human liver motion caused by breathing in the motion tracking experiment.

II. METHODS

In order to set up the tracking system and reduce the number of animal experiments for image-guided systems, a respiratory liver motion simulator is developed. It can be fabricated at low cost and is also possible to be used under computed tomography (CT) and magnetic resonance circumstances. Firstly, the principle of the simulator is illustrated in detail. Then comparisons are made between the movement generated by simulator and the motion of human liver.

The design of the respiratory phantom is based on the body structure. There are several key features which have been considered:

Phantom with target inside representing the liver with tumor. A two layers agar phantom has been fabricated to represent human liver with tumors regarding its ultrasound image properties.

A breathing balloon driven by the ventilator imitating the respiratory actuator

Viscous fluid (Polyacrylic acid solution) mimicking the fluid environment inside human body. Plexiglas® is selected as basic material because of its transparency, but other synthetic material would also be adequate.

A leak-proof box containing the individual components.

FIGURE 2 shows the principle of respiratory liver motion simulator. Simulation of the respiratory motion is achieved through an inflating/deflating balloon driven by a mechanical ventilator (Julian Anaesthetic Workstation, Germany) which control the breathing pattern. The balloon is surrounded by five faces, when air is blown into the balloon, it would expand in the direction of the missing sixth face. Subsequently, the balloon is in contact with the phantom and pushed the phantom forward. When the balloon deflated, the backflow of liquid would bring the phantom back, as well as the target inside. In this way, the phantom is able to move forward and backward periodically. Since the contact surface between the driving balloon and the phantom is not flat, the direction of pushing force would not stay the same, therefore, the movement of the phantom as well as the target inside are possibly moving in 2 directions, one main reciprocally direction and the other randomly direction perpendicular to the first. The performance of the motion simulator was tested and reported in the next section.

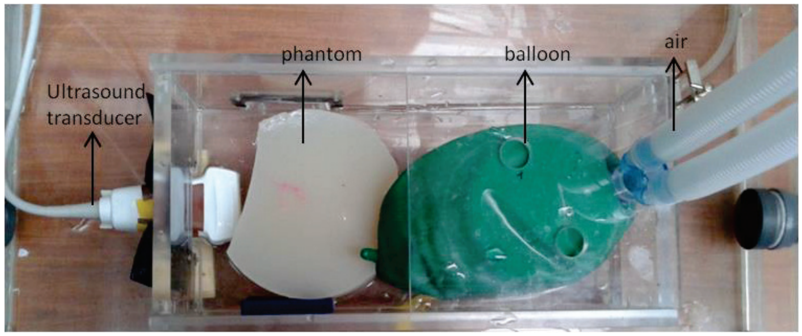

FIGURE 2: Photo of respiratory liver motion simulator

The respiratory motion simulator was then used to help conduct the HIFU tracking experiment (FIGURE 3). Instead of controlling a HIFU transducer to sonicate the phantom, a laser pen was attached onto the stage which could make the tracking effect more visually. At the same time, the target was changed into cylinder and part of the target was out of phantom. By this means, the relative position between target and focal point could be observed directly. Therefore, the error of robotic controlled motion tracking was visually shown.

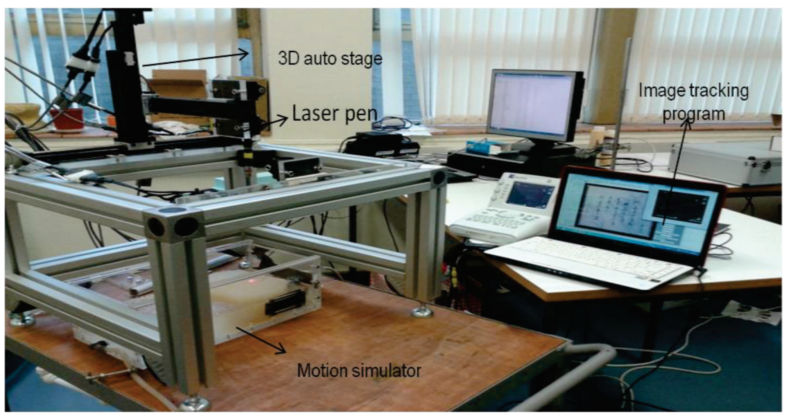

FIGURE 3: Schematic photo of experimental setup

As FIGURE 3 shows, when the phantom/tissue starts to move reciprocally, the ultrasound probe (Sonasite 180) would record the motion situation in sonography format and send the video to the image tracking workstation. The latter would calculate the relative motion distance between the two successive ultrasound image frames and return that value to the 3D stage which would guide the laser pointer or HIFU transducer to follow the target motion.

III. RESULTS

It has been investigated that the range of liver motion[4] for 20 patients are 3.0$\pm$2.0 mm, 5.1$\pm$3.1 mm, and 17.9$\pm$5.1 mm in the planning 4DCT for LR (left-right), AP (anterior-posterior) and CC (cranial-caudal) directions, respectively. The range of respiratory period is 3.9$\pm$0.7 mm during the 4DCT simulation. Table 1 summarized the comparison between the movement generated by simulator and the motion of human liver.

Table 1: Comparison between the motion of simulator and liver[4]

	CC (mm)	LR (mm)	AP (mm)	Cycle (s)	Tissue speed during breathing
Human Liver	17.9±5.1	3.0±2.0	5.1±3.1	3.9±0.7	
Simulator	Up to 20	2	unknown	3 to 7	controllable

At the CC direction, the simulator could provide enough motion range like real human liver, at the LR direction, the range provided is also comparable to real situation. Since there is no space allowable at the AP direction for the simulator, we've not measured the motion range at this direction. The motion cycles and the motion speed of the simulator is controllable so the simulator can mimick different liver motion speed caused by breath under different patient situations.

FIGURE 4 is a frame capture of the actual tracking experiment video, which shows the tracking effect. In the experiment, the laser point was considered as the HIFU focal point, expected to be locked on the target area when the phantom was moving forth and back. The laser beam was shined onto the surface of specially prepared phantom. The specially prepared phantom consists of two parts: PAA phantom and agar phantom with aluminum. During tracking process, the laser beam was capable of tracking the agar phantom inside which was considered as target, but with some motion time delay. This experiment also confirms the possibility of robotic controlled tracking using ultrasound image guidance.

(a) (b)

FIGURE 4: (a) Motion tracking effect shown by laser beam and (b)ultrasound image tracking

IV. CONCLUSION AND DISCUSSION

An ultrasound image processing technique for real time 2D target motion tracking and feedback correction was proposed and validated. The tracking algorithm could cope with different shape of target and deformation during tracking procedure[6]. To mimic the actual liver movement caused by human respiratory, a 2D motion simulator based on a medical ventilator was designed and fabricated. The characteristics of the simulator were tested and the parameters of the breathing motion range and speed could be adjusted corresponding to different experiment demands. The motion corrections were applied in near real time with the help of a 3D auto stage, which supposes to allow HIFU beam to be locked on target. The motion simulator and 3D stage guidance were synchronized and controlled by a Master workstation which executes the tracking program.

For the future work, the tracking performance will be tested under more sophisticated setup including tracking error estimation and HIFU sonication monitoring method investigation. It is thought that the tracking error will be mainly consist of two parts: image tracking error and motion time delay. The image tracking error only comes from the image process algorithm and the motion time delay is considered to be system error which mainly be constrained by hardware performance like the communication speed between image processing workstation and 3D stage.

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VI. REFERENCES

1. Kennedy, J. E. (2003). "High intensity focused ultrasound: surgery of the future?" British Journal of Radiology 76(909): 590-599.
2. Ter Haar, G. (2007). "Therapeutic applications of ultrasound." Prog Biophys Mol Biol 93(1-3): 111-129.
3. Alexander Stojadinovic, Peter J Allen, Craig D Shriver, Metastatic carcinoid tumour presenting as hepatic encephalopathy, HPB, Volume 4, Issue 1, pages 47–49, March 2002
4. Park JC, Park SH, Kim JH, Liver motion during cone beam computed tomography guided stereotactic body radiation therapy, Med Phys. 2012 Oct;39(10):6431-42
5. Auboiroux, V., L. Petrusca, et al. (2012). "Ultrasonography-based 2D motion-compensated HIFU sonication integrated with reference-free MR temperature monitoring: a feasibility study ex vivo." Phys Med Biol 57(10): N159-171.
6. X. Xiao, N. Le, G. Corner, G. Nabi, A. Melzer et al. Organ motion tracking in USgFUS - A feasibility study using sonoelastography AIP Conf. Proc. 1503, 135 (2012);